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by

Gordon English and Gerald Wilde

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Kingston, Ontario

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NOTICES

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16. Abstract

This study assessed the effectiveness of wayside horns at two grade crossings in Saguenay Quebec. The objectives were to assess the location specific: safety effectiveness, noise reduction effectiveness, and reliability of the wayside horn systems installed in Saguenay. The scope of work involved in-vehicle and on-site sound measurements and field tests of icing and snow ingestion. Safety effectiveness considerations include drivers stopped at grade crossings and drivers approaching grade crossings. Recommendations are made to modify the temporal pattern of the wayside horns, limit its duration and to set its health monitoring threshold to 92 dBA.

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16. Résumé

Cette étude a consisté à évaluer l'efficacité d'avertisseurs fixes (*wayside horn*) à deux passages à niveau de Saguenay, au Québec. Elle avait pour objectifs d'évaluer l'efficacité des avertisseurs fixes sur les plans de la sécurité et de l'atténuation du bruit, et leur fiabilité dans les conditions précises où ils avaient été installés, à Saguenay. Les tâches comportaient des mesures du niveau sonore dans l'habitacle de véhicules et à l'extérieur, ainsi que des essais sur le terrain de givrage et d'ingestion de neige. L'évaluation de l'efficacité sur le plan de la sécurité vise les conducteurs arrêtés à un passage à niveau et les conducteurs qui s'approchent d'un passage à niveau. Des recommandations génériques sont formulées, soit de modifier la séquence sonore du signal émis par les avertisseurs fixes, d'en limiter la durée à 55 secondes, et de fixer à 92 dB(A) le seuil de contrôle d'état.

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EXECUTIVE SUMMARY

There are potential benefits to the concept of locating an auditory warning system equivalent to a locomotive horn at some grade crossings rather than have the locomotive horn sounded. Having the sound closer and focused at the target location has potential to improve the ratio of warning-detection/community-annoyance in comparison with a locomotive-based horn. Even in the absence of a community noise concern, an auditory device located closer to the target recipient could improve the device's alerting effectiveness. There are no standards or guidelines for wayside horns (WSH) in Canada. Transport Canada and Canadian railways need to be in a position to identify the characteristics of wayside horns that are necessary to make them effective, or at least safety-neutral in comparison with the locomotive horns they are replacing.

The Roberval and Saguenay Railway (CFRS) with the Quebec Ministry of Transport (MTQ) have installed wayside horns at two railway crossings in Saguenay (the former city of Chicoutimi), Quebec. They are the first (and so far only) installations of the technology in Canada. This presented an opportunity for Transport Canada and Canadian railways to assess the safety, reliability, noise and community acceptance issues associated with the technology.

In a safety-neutral comparison with the existing CFRS locomotive horns and under Saguenay conditions, the WSH provided a higher sound pressure level (SPL) to stopped vehicles. However, it provided a lower SPL to approaching vehicles at a location down the road where drivers need to hear it in time to react and stop. In terms of the sound output level required to attain the necessary auditory alerting inside an approaching vehicle (for Saguenay conditions and irrespective of the regulatory minimum requirement), the WSH was considered adequate for situations with fast driver response time and dry pavement, even though it provides a lower SPL than the locomotive horn. However, the WSH would alert far fewer drivers than the CFRS locomotive horn in the case of slower driver response and wet pavement. The addition of slave speakers farther down the road and closer to approaching vehicles was recommended for one of the grade crossings.

Since the fixed on-off pattern of the WSH has no ability to adjust to circumstances, and the existing railway whistling pattern itself has no safety basis, it is recommended that it be modified to a repeating pattern of 3.5 seconds on and 1 second off. In this way, there are no intervals exceeding one second without warning, or requiring detection and recognition of the warning within the time interval of a one-second sound signal.

The dilemma, which is characteristic of North American grade crossing warning systems, can be exacerbated if the WSH is activated immediately with the flashing lights; but can be avoided if the WSH activation is delayed. It is recommended that WSH technology only be deployed at crossings that either have consistent warning times with few false alarms, or where the WSH can be tied into a separate activation system that can provide consistent warning times, which fall within the times recommended in Transport Canada's whistle ban guidelines. Since false alarms can never be totally eliminated, it is recommended that the WSH should be:

a) activated with, at minimum, a 4 second delay, and with enough delay to provide at most the design warning time for the crossing.

b) deactivated when the locomotive passes through the crossing, subject to the time constraint that if the train is not detected to have passed through the crossing within 55 seconds, the WSH should be turned off and the health monitor system triggered to provide the locomotive engineer with an indication that the system has been turned off.

Since the design warning time can be shorter than the locomotive horn's warning time for slow trains (as initiated at the quarter-mile whistle post), it is recommended that the whistle post be moved in to a distance that is consistent with the design warning time for crossings with train speeds less than 40 km/h (25 mph).

It is recommended that the health monitoring system be set to activate when the SPL output from any speaker either drops by 3 dB from the installed certification level, or falls below the equivalent output of 92 dB(A) at 30.5 m. (100 ft.). We further recommend that any installation in regions susceptible to freezing rain or blowing snow have this threshold of the health monitoring system verified once a year in the fall or early winter.

CONTENTS

1. Introduction 1
   - 1.1. Previous Studies 1
   - 1.2. Saguenay Study Grade Crossings 4
   - 1.3. Evaluation Approach 6
     - 1.3.1 Sound Characterization Definitions 6
     - 1.3.2. Auditory Alerting Requirements 7
   - 1.4. Report Structure 8

2. WSH Characterization 9
   - 2.1. Sound Characteristics 9
     - 2.1.1. Role of Ground Effects 10
   - 2.2. Activation and Timing Cycle 12
     - 2.2.1. On-Off Pattern While Activated 12
     - 2.2.2. Start and Stop Times 13
   - 2.3. Directionality: Data and Issues 15
     - 2.3.1. Trespassers 16
     - 2.3.2. Train Approach Direction Information 16

3. School Bus Characterization 19

4. Safety Effectiveness 22
   - 4.1. Stopped Vehicles 22
   - 4.2. Approaching Vehicles 23

5. Community Noise Impacts 29

6. Winter Reliability 31

7. Conclusions and Recommendations 33

8. References 36

LIST OF FIGURES

Figure 1 Photograph of Boul. Talbot grade crossings 5
Figure 2 Photograph of Boul. St. Paul grade crossing 6
Figure 3 Comparison of WSH and locomotive horn spectra 9
Figure 4 Ground effects on received sound at 61 and 30 m 11
Figure 5 Comparison of Fann's data with ground effect predictions 11
Figure 6 WSH temporal pattern at Saguenay 12
Figure 7 Illustration of left turn geometry at a grade crossing 17
Figure 8 Background noise in stationary school bus 19
Figure 9 School bus insertion loss with door closed and door open 20
Figure 10 Warning distance comparison for WSH and locomotive horn 24
Figure 11 Alerting SPL comparison at St. Paul 25
Figure 12 Spectrogram of the in-vehicle sound recording without slave speaker 26
Figure 13 Spectrogram of the in-vehicle sound recording with slave speaker 26
Figure 14 In-vehicle sound spectra comparison at 45 m. from St. Paul crossing 27
Figure 15 Community noise impact comparison (St. Paul – left, Talbot – right) 29
Figure 16 Community noise impact comparison at St. Paul with slave speakers at 30 m 30
Figure 17 Photograph of WSH speaker filled with snow 32

LIST OF TABLES

Table 1 Directionality data from Fann's WSH measurements 15

GLOSSARY

CWT	Constant warning time.
FRA	U.S. Federal Railroad Administration
MWD	Minimum warning distance required for the conditions of a given scenario.
NTSB	U.S. National Transportation Safety Board
SEL	The *Sound Exposure Level* describes the cumulative noise exposure from a single noise event for its entire duration. In calculating SEL, the noise exposure is normalized to a time duration of one second so that different noise events can be compared in terms of their sound energy.
S/M	Signal-to-mask ratio, where the mask is the effective masking influence that background noise has on human hearing.
SPL	Sound pressure level measured in decibels (dB) with respect to a reference level of 20 micropascals.
WSH	Wayside horn.

1. INTRODUCTION

1.1 Previous Studies

There are potential benefits to the concept of locating an auditory warning system equivalent to a locomotive horn at some grade crossings rather than have the locomotive horn sounded. Having the sound closer and focused at the target location has potential to improve the ratio of warning-detection/community-annoyance in comparison with a locomotive-based horn. Even in the absence of a community noise concern, an auditory device located closer to the target recipient could improve the device's alerting effectiveness. However, the effectiveness comparison is not that straightforward. Providing a horn-like sound at a grade crossing can involve different technology and new operating practices.

The wayside horn concept tested in the U.S. has been stimulated by community noise concerns in response to the U.S. Federal Railroad Administration's (FRA) move to eliminate all whistle bans. The systems have involved electronic loudspeakers mounted at the crossing. They play a simulated locomotive horn sound and are enclosed/shielded so that the sound output is focused along the highway rather than along the track. The horns are triggered by the crossing signal system and include a strobe light, which indicates to the locomotive crew that the horn has been activated.

The wayside horns tested thus far in the U.S. have been assessed in some detail with respect to community noise impact and have enjoyed a high level of community acceptance. The Volpe Center conducted an early assessment of horn effectiveness [Rapoza, Raslear and Rickley, 1999] that used a single-flute wayside horn as characterized in an earlier 1993 study [Keller and Rickley, 1993]. It was assessed as being unable to be detected inside a vehicle at the required warning distance for speeds of 30 mph and higher.

The acoustic characteristics of the wayside horn were subsequently improved to provide the recorded sound of a locomotive horn and emit a louder signal (about 92 dB compared with the earlier 87 dB). This improved system was used in later demonstration sites.

A detailed review of the WSH concept was undertaken for an installation in Gering, Nebraska [Multer and Rapoza, 1998]. The study found a reduction in community noise—"The wayside horn tested is considerably less annoying than the train horn". However, the study raised several safety-relayed concerns that it could not directly measure. These concerns were summarized in the FRA's notice of proposed rule making [U.S. DOT, FRA, 2000] with respect to locomotive horns, where it noted that the evaluation

> *did not permit a determination of whether a wayside horn could fully substitute for a train- borne audible warning. At least three questions must be answered in this regard:*
>
> 1. *Does the particular system provide the same quality of warning, determined by loudness at appropriate frequencies, within the motor vehicle while it is approaching the motorist's decision point?*

2. *As currently conceived, a single stationary horn cannot give the motorist a cue as to the direction of approach of the train or trains. To what extent does this lack of directionality detract from the effectiveness of the warning? Can wayside installation design be altered to compensate?*
3. *To what extent will the stationary horn suffer from the lack of credibility sometimes associated with automated warning devices, due to the fact that it is activated by the same means? Over what period of time may this problem arise, if at all?*

FRA will continue to identify opportunities for developing data and analysis that may be responsive to these questions. However, for the present it is not possible to have confidence that the wayside horn can fully compensate for the absence of the train horn at any individual crossing.

The FRA's final position on wayside horns was issued with its final rule on locomotive horns [U.S. DOT FRA, 2005]. It set forth the following minimum requirements for wayside horn use as an acceptable alternative to locomotive horns at automated highway-rail grade crossings in the U.S.:

1. *Highway-rail crossing must be equipped with constant warning time device, if reasonably practical, and power-out indicator;*
2. *Horn system must be equipped with an indicator or other system to notify the locomotive engineer as to whether the wayside horn is operating as intended in sufficient time to enable the locomotive engineer to sound the locomotive horn for at least 15 seconds prior to arrival at the crossing in the event the wayside horn is not operating as intended;*
3. *The railroad must adopt an operating rule, bulletin or special instruction requiring that the train horn be sounded if the wayside horn indicator is not visible approaching the crossing or if the wayside horn indicator, or an equivalent system, indicates that the system is not operating as intended;*
4. *Horn system must provide a minimum sound level of 92 dB(A) and a maximum of 110 dB(A) when measured 100 feet from the centerline of the nearest track;*
5. *Horn system must sound at a minimum of 15 seconds prior to the train's arrival at the crossing and while the lead locomotive is traveling across the crossing. It is permissible for the horn system to begin to sound simultaneously with activation of the flashing lights or descent of the crossing arm;*
6. *Horn shall be directed toward approaching traffic.*

The Iowa Department of Transportation undertook an evaluation [Gent, Logan and Evans, 1999] of an automated horn warning system at three highway-railroad grade crossings in Ames, Iowa. This study was based on sound level measurements and surveys of residents, motorists and train engineers. The study provided the following findings:

- The stationary horn reduced the area with noise levels greater than 80 dB(A) by 97 percent, from 171 acres using the train horns to less than 6 acres using the stationary horn. It also reduced the dB(A) level in its path and the area closest to the crossing.

- The residents overwhelmingly accepted the automated horn system. 77 percent of the residents indicated the train horns had either a negative or very negative impact on the quality of life, compared to only 3 percent in the after condition (stationary horn)
- 78 percent of motorists surveyed preferred the automated horn system, 8 percent preferred the train horn, and 14 percent had no opinion
- 92 percent of train engineers rated the overall safety at the crossings with the automated horn system to be the same or safer, compared to the before (train horn) condition.
- 73 percent admitted to blowing the train horn at least once at the subject crossings after the automated horns had been installed. The primary reasons for blowing the train horns were: a) concern related to motorist or pedestrian behavior at the crossing, and b) old habits are hard to break.

While the study reaffirmed the effectiveness of the wayside horn system in reducing community noise concerns, it did not resolve any of the safety issues raised in the Gering study.

Somewhat in contrast to the positive feedback from interviews with participating locomotive engineers, the Brotherhood of Locomotive Engineer's official position (as presented in the June 2000 issue of its newsletter *The Locomotive Engineer*) raises (in part) the following issues:

> *... Another concern is the possible diminution of the wayside horn's effectiveness over time. We know that many motorists ignore signs, bells and lights, and go around gates for a variety of reasons, not the least of which is a presumed familiarity on the motorist's part with the time between the beginning of these signals and the actual arrival of a train. Will the wayside horns come to be viewed over time in this same way by such motorists? Will these motorists come to ignore this safety device, too? Wayside horns also introduce the added problem of always having a noise impact in the vicinity of the crossing. Finally, the issue of false activation of the wayside horn should be addressed before consideration is given to using them.*

A more recent WSH evaluation was undertaken by Northwestern University [Raub, Lucke et al., 2003] for the city of Mundelein, Illinois. Mundelein installed a total of nine wayside horns at gated crossings with highway approach speed limits ranging from 25 mph to 55 mph. The evaluation study monitored three of the nine crossings, all of which had speed limits of 30 mph, one of which ha d a 15 cm median curb for about 12 m back from the crossing.

The Mundelein installation was the first one using fixed distance track circuits— both of the previous locations used constant warning time (CWT) track circuits. Mundelein also has train operating patterns that exacerbated the problems of fixed distance track circuits (i.e. passenger train stops and switching moves that triggered false alarms). One resulting observation was that the long warning times and false alarms could lead to increased violations by pedestrians who are exposed to a louder signal than the previous crossing bell.

Additional issues were also raised with respect to driver behaviour. There were six incidents of motorists who upon hearing the onset of the wayside horn (which is activated at the same time as the flashing lights) stopped on the tracks and sat for a period of time before deciding what to do. Some drivers backed up, others went forward. The exposure time on the crossing tracks was up

to 12 seconds after warning initiation. The observed behaviour was attributed to the startle effect of an abrupt onset of the AWHS (automated wayside horn system). The authors made a couple of suggestions:

> *The current operation of the AWHS could be likened to mounting a fire siren at an intersection and having it sound the moment the traffic signal turns yellow. It may be more desirable for motorists to be given some prior warning that the horn is about to sound, such as activating the warning lights first. A second might be to start the wayside horn at a lower decibel level (akin to the train horn first being heard at a distance from the crossing) before bringing it to full volume.*

All three of the wayside horn studies showed reductions in those violations that occur before the gate is down, but no statistically significant difference in violations after the gate had descended. A follow up study at Gering Nebraska in 2000 was undertaken by the Texas Transportation Institute [Roop, 2000] several years after Volpe's 1995 field test. It found the type 1 violations (prior to gate down) had returned to the frequency measured prior to the introduction of the WSH—about 19 per-thousand trains, which was double the frequency observed for the WSH in the introductory test. Comparisons of "gate down" violations can not be made since the latter study excluded false activation violations, while the first study did not. Even if the numbers are adjusted to allow such a comparison, the frequency of high-risk violations at these sites are so low that even a six-month monitoring program did not observe statistically significant frequencies of high-risk events. Ignoring false activation of the signal system, the first study observed one type-2 violation for the train-horn state (0.4 per thousand trains) while the 2000 study observed none.

The fact that all of the previous studies involved up to six months of video monitoring at crossings that saw large numbers of road and rail traffic highlights the problems of trying to assess technology effectiveness via short duration pilot projects.

1.2 Saguenay Study Grade Crossings

The FRA included wayside horn technology (with associated installation conditions) as Substitute Safety Measure (SSM) for communities seeking a whistle ban. SSMs are approved engineering alternatives that the FRA deems to be an effective substitute at any gated crossing. However, there are no standards or guidelines for wayside horns (WSH) in Canada. Transport Canada and Canadian railways need to be in a position to identify the characteristics of a wayside horn that are necessary to make it at effective, or at least safety-neutral in comparison with the locomotive horn it is replacing. It would also be desirable to know whether it can provide a cost-effective alternative to other measures that are presently recommended for crossings where a whistle ban is being considered.

The Roberval and Saguenay Railway (CFRS) with the Ministry of Transport Quebec (MTQ) have installed wayside horns at two railway crossings in Saguenay (the former city of Chicoutimi), QC. They are the first (and so far only) installations of the technology in Canada. It presented an opportunity for Transport Canada and Canadian railways to assess the safety, reliability, noise and community acceptance issues associated with the technology. The

Saguenay installation provided an opportunity to collect data in a form that is specifically suited to assessment of the technology in other Canadian locations.

Boulevards Talbot and St. Paul (see Figure 1 and Figure 2 respectively) are the two main arterial roads into the city. Both crossings have 70 km/h posted highway speeds and the train speed is 30 mph. The highways have a median 15 cm. curbed island dividing the highway and there are dual gates on each side, which provide a full-width barrier for traffic in each direction. The crossings have cantilever mounted large-size (30 cm) flashing lights over each of the traffic lanes (six at Talbot, four at ST. Paul). In addition, Talbot has an interface with the adjacent road intersections which provide a 30 second preemptive clearing/stopping at the road intersections followed by a 30 second FLB warning at the crossing. The objectives of this study are to assess the location specific:

- safety effectiveness,
- noise reduction effectiveness, and
- winter reliability of the wayside horn systems installed in Saguenay.

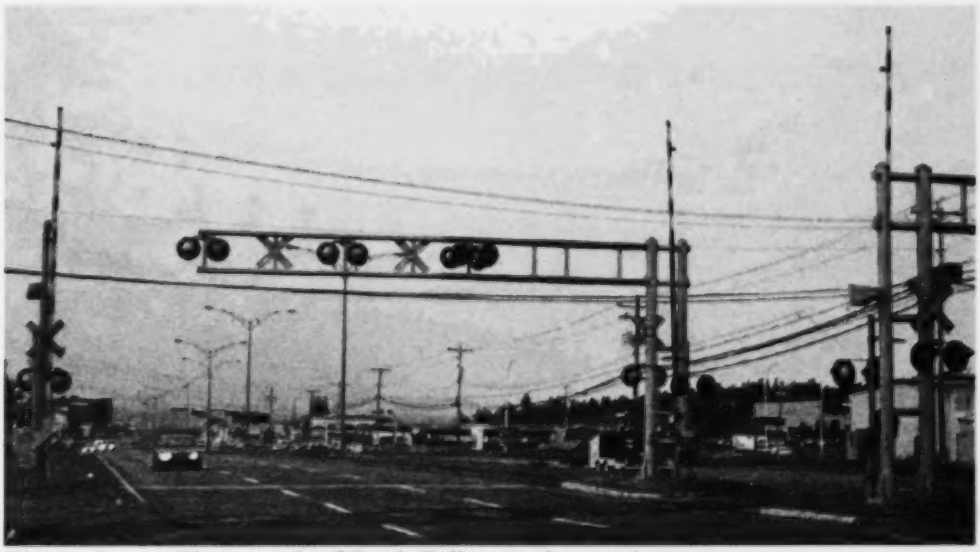

Figure 1 Photograph of Boul. Talbot grade crossings

Figure 2 Photograph of Boul. St. Paul grade crossing

1.3 Evaluation Approach

Since this is a location-specific assessment, the safety effectiveness involves an assessment of the safety equivalence with the existing locomotive horns used by the CFRS. Our approach in this study draws upon the findings and methodologies used in a previous evaluation of locomotive horns that was undertaken as an earlier Direction 2006 initiative [English et al. 2003]. Our safety effectiveness assessment for CFRS locomotive horns and Saguenay WSHs uses the same in vehicle alerting criteria and methodology as was used in that study. Some of the relevant definitions and concepts outlined in that study are repeated here in the remainder of this section.

1.3.1 Sound Characterization Definitions

Sound measurement is typically made with instruments that measure pressure variation. Sound pressure level (SPL) is usually measured with respect to a reference level (Pref) of 20 micropascals. People's perception of loudness is not linear. An SPL measurement (Pmeas) is usually related on a log (base-10) scale in decibels (dB) where:

$$SPL\ (dB) = 10\ LOG(Pmeas / Pref) \quad (1)$$

Because sound is measured on a log scale, each 3 dB rise relates to a doubling of sound level (i.e. 10 LOG(2) ~ 3). However, it takes a sound level increase of approximately 10 dB before someone will subjectively perceive a doubling of loudness.

A sound signal can be characterized by the relative magnitude of its underlying pure-tone frequency components. Locomotive horns can be characterized within the frequency range (or spectrum) of its lowest fundamental frequency (311 Hz for most Canadian locomotive horns) up

to the 7th harmonic (or overtone) of its highest fundamental (i.e. 7 X 622 = 4,354 Hz for a 5-flute horn).

The human ear does not perceive all frequencies equally, and sound measurement is often "adjusted" to reflect the way the human ear interprets sound. An A-weighted sound level, abbreviated "dBA", indicates that the sound has been filtered to reduce the strength of very low and very high frequency sounds, much as the human ear perceives sounds of low intensity. Without this A-weighting, noise-monitoring equipment would respond to noise events people cannot hear, such as high-frequency dog whistles and low-frequency seismic disturbances. Where spectral measurements are taken, a linear scale is often used; however, only the frequencies of interest are included in the subsequent analyses.

Sound frequency is also usually related on a log scale. A doubling of frequency represents a change of one octave. To characterize a sound's frequency spectrum, its SPL is aggregated within a specified bandwidth and referred to as the centre point of each band. Sound level meters and much of the literature describe sound measurements on the basis of octave or 1/3-octave bands. Bandwidths of 1/3 octave are used for most of the measures in this report.

Community annoyance with unwanted noise involves more than its loudness. The time of day that it occurs, its frequency spectrum, the duration/frequency of occurrence, and its tonal qualities all have an influence. Since the locomotive horn and the wayside horn occur at the same time of day but can have different durations, we use the following cumulative noise exposure measure as the basis of comparing community noise impacts:

- SEL, the *Sound Exposure Level*, describes the cumulative noise exposure from a single noise event for its entire duration. In calculating SEL, the noise exposure is normalized to a time duration of one second so that different noise events can be compared in terms of their sound energy.

1.3.2 Auditory Alerting Requirements

As in the locomotive horn study the minimum warning distance formula suggested by Aurelius and Korobow [1971] was adopted with one modification. The distance between locomotive horn and highway vehicle is a combination of the minimum distance from the crossing that each vehicle must be at to have a safe warning. The critical distance for the highway vehicle is a combination of the distance travelled during the driver's reaction time (after being alerted to the presence of the train) and the minimum braking distance for its speed and the road friction conditions. Mathematically this minimum warning distance (MWD) is:

$$MWD = V_m / 3.6T_{br} + V_m^2 / 255(f \pm g) \qquad (2)$$

where:

V_m = motor vehicle speed (km/h)
T_{br} = brake reaction time of the driver (s)

g = road approach gradient
f = assumed tire-ground friction coefficient

To determine the location of the train coincident with this point in time, Aurelius defines a critical time (T_{cr}). This is the time required for the highway vehicle to safely clear the crossing before the train crosses if the driver did not hear the warning a microsecond before the MWD was reached. This time is defined as:

$$T_{cr} = (MWD + CTZ + L_v)/V_m \quad (3)$$

où :

V_m = motor vehicle speed (m/s)
CTZ = critical track zone length (m)
Lv = motor vehicle length (m).

The train's distance from the crossing associated with T_{cr} is the product of the train speed and T_{cr}. For higher speed trains, the speed of sound becomes a relevant delay. Thus, in a slight departure from Aurelius's methodology, we have taken one iterative step in determining the train's required warning distance. First, the travel distance of the horn sound waves is calculated as the hypotenuse associated with the two above distances and the crossing angle. We then adjust the train distance back an additional distance associated with the time delay in the sound leaving the horn and arriving at the motor vehicle.

In a further modification to Aurelius's methodology, we assess the following two levels of performance:

1. The generally accepted highway design standards in their calculations (2.5 s of reaction time and about a 0.35 coefficient of friction).
2. To determine the point at which a horn begins to have an influence, we adopt a less stringent effectiveness criteria of 0.6 s reaction time and 0.6 friction coefficient.

1.4 Report Structure

This report is presented in seven chapters. The following topics are addressed in the balance of the report:

- Chapter 2 presents findings on the sound characterization of the Saguenay wayside horns.
- Chapter 3 presents our findings on the characterization (insertion loss and background noise) of school buses.
- Chapter 4 presents findings on the safety effectiveness of the wayside horns at Saguenay.
- Chapter 5 presents findings on the community noise impact of the wayside horns at Saguenay.
- Chapter 6 presents findings on the winter reliability of the wayside horns at Saguenay.
- Chapter 7 presents conclusions and recommendations.

2. WSH CHARACTERIZATION

2.1 Sound Characteristics

Our scope of work called for an assessment of the WSH to determine if it was safety neutral to the locomotive horns presently used by the CFRS at those grade crossings. Thus, we took SPL measurements for the two wayside horn installations at Saguenay and also for a CFRS locomotive. Figure 3 presents the frequency spectrum of the SPL measurements taken at 61 m. down-road from the WSH at St. Paul, and 61 m. lateral from the 3-flute CFRS locomotive horn. The spectral content of the WSH covers a similar range to that of the CFRS locomotive horn. While the WSH drops off faster at frequencies below 400 Hz and above 3150 Hz, the variation inside that range is comparable to the locomotive horn. The spectral content conforms to our recommended spectral content for locomotive horns for train speeds below in 105 km/h. We recommended that at train speeds below 105 km/h the minimum 1/3 octave band SPL in the 2000-3150 Hz range, be not less than 15 dB below the maximum 1/3 octave band SPL in the 250-1250 Hz range, and the WSH difference is 14.4 dB (87.3 at 1,250 Hz and 72.7 at 3,150 Hz).

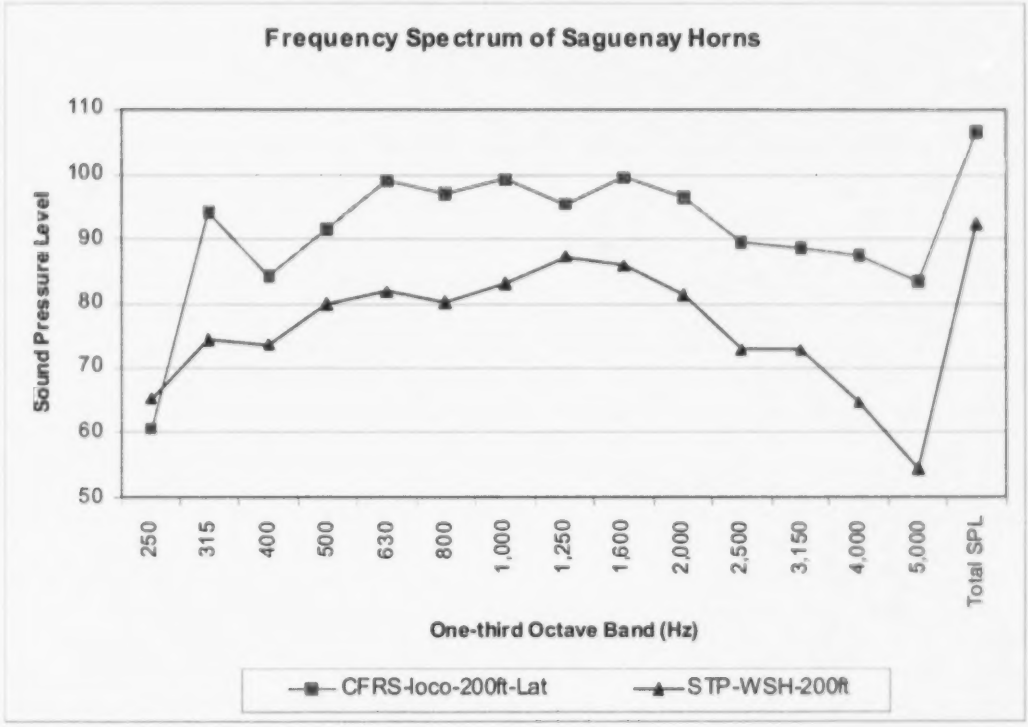

Figure 3 Comparison of WSH and locomotive horn spectra

One can see from Figure 3 that the total sound pressure level for the WSH is about 12 dB lower than that of the CFRS locomotive horn. Measurements were also taken at 31 m. and did not differ significantly from those at 61 m. The WSH produces a SPL of 92 to 95 dB(A) at 30.5 m. (100 ft.) from the horn. This meets the FRA's new horn rule, which requires a WSH to provide 92 dB(A) at 100 ft. (30.5 m.) from the horn. The CFRS locomotive horns produce a SPL of 106

to 108 dB(A) at 30.5 m. from the horn. The locomotive horn's output level is higher than the regulatory minimum for locomotive horns of 96 dB(A) but some of the increment is a consequence of the position on the locomotive that requires a higher SPL at source to provide the 96 dB required at 30.5 m. in front of the locomotive.

As discussed in more detail in Chapter 4, the higher output of the locomotive horn is mitigated to some extent when compared with the WSH, because the locomotive is farther from the crossing when it must be heard. This impact will be greater the higher the speed of the train.

2.1.1 Role of Ground Effects

There is a lack of agreement of data from the basic sound characterizations of previous WSH tests. Some of the early measurements were made with speaker systems that have since been upgraded. However, the two most recent measurement reports that we could locate and our measurements do not agree in the basic SPL and frequency spectrum of speakers from the same supplier. The two locations that were measured in Mundelein showed SPLs of 92 and 94 dB(A) at 110 ft. while the WSH characterization measurements reported by Fann indicate a level of 98 dB(A) at 100 ft. [Fann, 2000]. Fann also found variations with distance that differed from the theoretically expected fall off value of 6 dB per distance doubling.

Ground effects are known to influence the sound characteristics. Even in an open area where sound reflections form walls can be avoided, the reflected sound from the ground will influence the sound signal that travels directly form source to receiver. The two paths of a sound signal are combined at the receiver are influenced by two factors. First, the path taken by the reflected signal involves a longer distance and produces a phase shift between the signal taking the direct path and the signal taking the reflected path. The degree of phase shift is influenced by the heights of the sound source and the receiver, as well as the distance between them. The phase shift has a different impact for each frequency/wave-length component in the sound source. When the two signals are combined at the receiver, the amplitude (or sound pressure level) of some frequencies can be enhanced and others mitigated over that of the signal taking the direct path. The second influence is the type of surface involved – hard surfaces will have little attenuation of signal strength and soft absorbing surfaces will have a greater attenuation of the reflected signal. The combined effects can be quite complex, even for the simple geometry of a uniform flat ground surface.

We explored the influence of ground effects at separation distances (between sound-source and receiver) of 30.5 m (100 ft.) and 61 m. (200 ft.) using the ground effects sub-module in the Community Noise Model of the University of Central Florida [University of Central Florida, 2002]. The ground effects sub-module is based an implementation of Rudnick's algorithm [Rudnick, 1947]. Figure 4 illustrates the theoretical predictions of SPL enhancement due to ground effects over the frequency range zero to 5,000 Hz. The assumed conditions are a hard surface, with source mounted at a height of 3.7 m. (12 ft.) above ground and a receiver at a height of 1.2 m. (4 ft.) above ground. One can see that there are significant differences in influence at the two distances. The largest difference occurs at 1,100 Hz. where the SPL is augmented by 5 dB at 30 m. source-receiver separation distance and attenuated by 20 dB at 61 m. source-receiver separation distance.

Figure 5 plots the difference between the ground effects associated with the two distances plotted in Figure 4 and compares it with the data points measured by Fann. One can see that there is reasonable agreement in the data. The results highlight the fact that independent measurements of the same technology can have sizable differences at specific frequencies. We explored the effect of varying heights of the WSH on the received signal and determined that, while some improvement in alerting qualities was realized with higher mounted speakers, the influence was not significant enough to warrant a recommendation to mount the WSH any higher than the existing 3.7 m. (12 ft.).

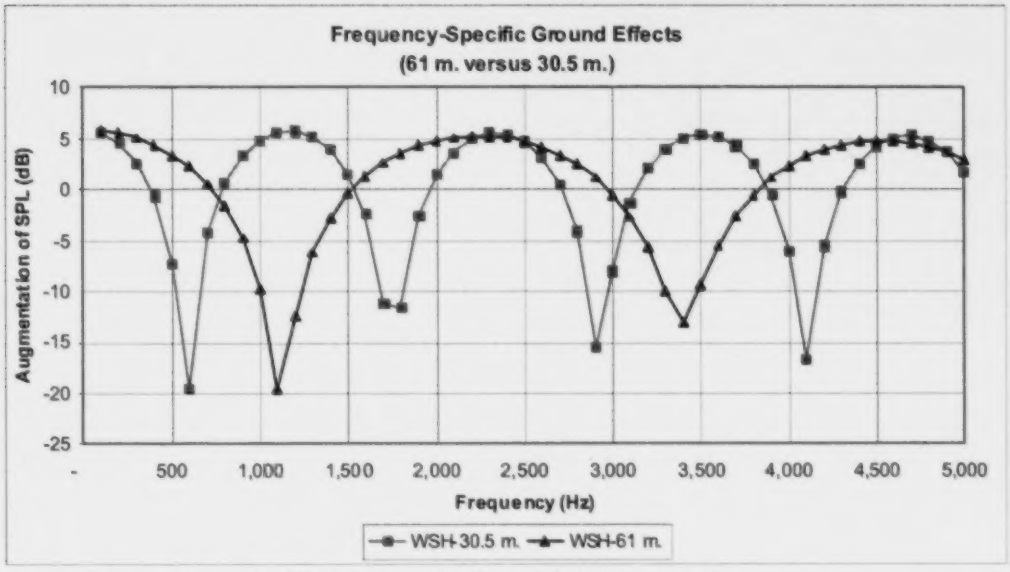

Figure 4 Ground effects on received sound at 61 and 30 m.

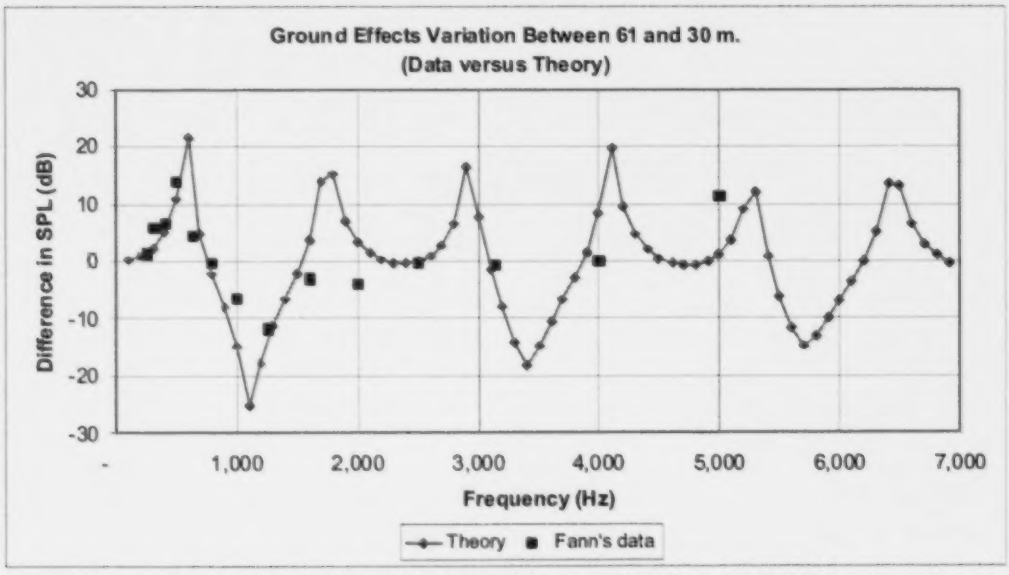

Figure 5 Comparison of Fann's data with ground effect predictions

2.2 Activation and Timing Cycle

The following two aspects of the WSH activation cycle are discussed in this section:

1. the on-off pattern while activated, and
2. the start and stop times for the system activation.

2.2.1 On-Off Pattern While Activated

The temporal pattern of the WSH is illustrated in Figure 6. The system is tied into the track circuit and is activated with the flashing lights and bell at the crossing. The produces a sound pattern that simulates the railway operating rule 14(L)(ii) which dictates locomotive engineers apply an on-off whistle pattern of two longs, a short and one more long when approaching a crossing. The WSH system does not use the exact rule, but applies the whistle pattern assuming a 60 mph (97 km/h) train and repeats that pattern until the locomotive arrives and passes through the intersection.

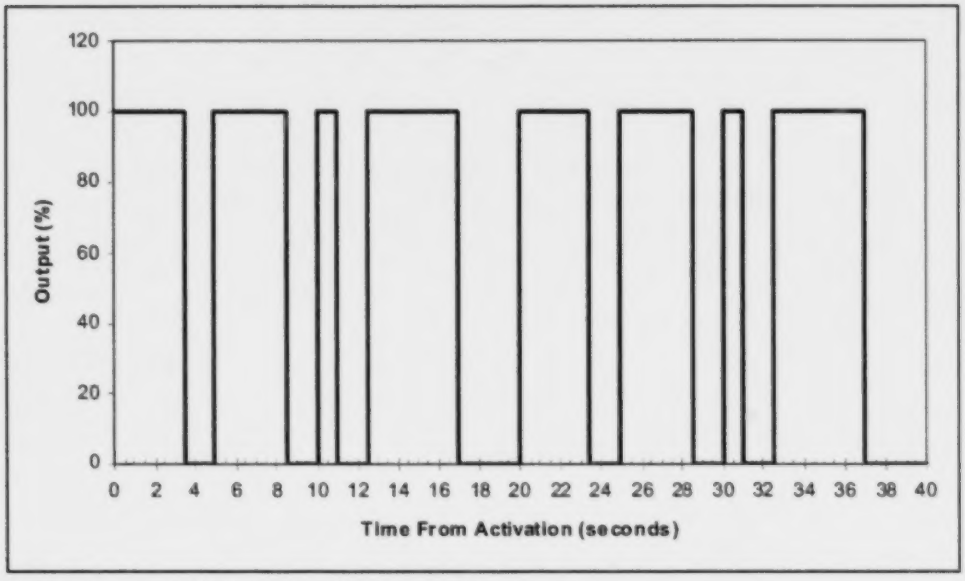

Figure 6 WSH temporal pattern at Saguenay

The locomotive engineer can adjust the whistle pattern in cases where a hazardous situation exists. The critical time interval for an alerting signal to be received by a driver approaching at 70 km/h is when the vehicle is 3 to 6 seconds from the crossing. The corresponding time from activation of the WSH will vary with train speed. For the base case conditions of 30 mph train speed the interval is 21 to 24 seconds after activation. One can see from Figure 6 that there is a possibility of the critical time period occurring when the WSH is in its 3 second dwell period between cycles, or in the 4.5 second interval when there is only a 1 second activation for the 'short' activation of the rule 14(L)(ii) whistle pattern. The whistle pattern itself has no safety relevance, and the fact that the WSH only follows that pattern for one specific train speed, means there is no argument in favour of using it. Since the fixed pattern of the WSH has no ability to

adjust to circumstances, and the pattern itself has no safety basis, it is recommended that it not be used in WSH applications. Rather, it is recommended a fixed pattern of 3.5 seconds on and 1 second off. In this way, there are no intervals exceeding one second without warning, or requiring detection and recognition of the warning within a one-second sound signal.

2.2.2 Start and Stop Times

2.2.2.1 Exacerbation of the *driver-dilemma* period

A key difference between road-road intersections and road railway grade crossings is the lack of a pre-warning aspect in the railway case. Grade crossings do not have the yellow change of state pre-warning that exists at road-road intersections.[1] Drivers who are close to a railway crossing when it starts to flash are faced with a dilemma of whether to stop (knowing they can not do so safely and/or comfortably), or keep going and break the law. The lack of a pre-warning at grade crossings is one factor in the accident statistics at grade crossings. Schoppert and Hoyt [Schoppert and Hoyt, 1968] first identified the phenomenon that 2/3rds of the accidents that occur at grade crossing do not involve trains but are due to driver uncertainty and inter-vehicle speed variation approaching crossings. Dodson found similar ratios in an updated 1989 study and in an assessment of the influence of school bus stopping policy in 1996 [Dodson, 1996].

The introduction of an audible warning reinforces a warning system that already poses a dilemma to the driver and could exacerbate the existing problems of unpredictable speed variation in approaches to grade crossings. Laub et al. [Laub, et al., 2003] found indications of the exacerbated effect of the WSH at Mundelein. They reported six cases of motorists who, upon hearing the onset of the horn sound, stopped and remained motionless in the middle of the tracks for up to 12 seconds. No instances were reported for the normal signal system with locomotive horns. The action of these six drivers could very well lead to rear end collisions and in the worst case, stalled vehicles on the track that would lead to a train collision. It could be that the unexpectedly high number of occurrences was affected by the publicity surrounding the pilot test. Some people may have viewed a successful test as being important to the community and the immediate stops were misguided attempts to give the desired response of obeying the new horn. Regardless of the proportion of real startle effects in the number of observations, some influence can be expected.

This exacerbated dilemma situation can be eliminated by delaying the activation of the WSH. It is recommended that the WSH be activated after an initial delay of at least 4 seconds. As further discussed below, it is recommended a longer delay be built in for areas with slow train speeds.

2.2.2.2 Duration of Warning Signal

The standard grade crossing warning system can be prone to false alarms and long/highly-variable warning times. The locomotive horn, on the other hand provides an indication that the

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[1] It should be noted, though that even with forewarning, the installation of traffic lights at intersections tends to lead to an increase in rear-end collisions. For a review of the evidence, see Wilde, G.J.S. (2001). Target Risk 3. Toronto: PDE Publications, p.122.

train is actually present. The association of hearing the locomotive horn with the train's actual presence (if not imminent arrival) could be the main factor in its effectiveness.

The WSH system is activated by the track circuit along with the flashing lights and bell at the crossing. As such it is effectively replacing one warning system (which provides incremental information on the presence of a train) with a warning that is completely redundant with the visual warning, adding no incremental information and repeating all the misinformation. Multer and Rapoza [1998] raised the issue of signal system activation in its first study of WSH technology at Gering Nebraska.

> *[....] for the wayside horn, the motorist will learn that the auditory warning is not always associated with a nearby locomotive, to the extent that false activations occur. The implications of this association are threefold. First, the motorist may be more likely to disregard auditory warnings at crossings with wayside horns. Second, the motorists' disregard for auditory warnings may generalize to situations where the auditory warning is on the train*[2].

They also observed that:

> *an increased level of false activations at one grade crossing may have contributed to an increased level of noncompliance. Motorists were more likely to drive around the gates when the number of false activations increased.*

These concerns have been addressed in the U.S. by only installing WSH systems at crossings that use constant warning time (CWT) devices. Predictor circuits measure train speed and use that information to predict arrival time. Activation of the crossing warning system is delayed for slower trains such that a close to constant warning time is provided.

However, CWT signal systems do not avoid false alarms in all circumstances (e.g. a passenger station stop or a switch lead near the crossing). Also, some locations have very uniform train speeds and provide a consistent warning time without actual predictor circuits. This is the case at Boulevards St. Paul and Talbot in Saguenay.

It is recommended that WSH technology only be deployed at crossings that either have consistent warning times with few false alarms, or where the WSH can be tied into a separate activation system that can provide a consistent warning. Since false alarms can never be totally eliminated, we believe the duration of the WSH warning time should be limited to be consistent with the recommendations made for active warning systems in Transport Canada's Draft Technical Standard RTD10.[3] The guidelines suggest that approach warning times of an automatic warning system should not be more than 13 seconds longer than the standard design warning time, and never exceed 55 seconds. The design warning time is dependent on the local

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[2] The study also expressed a third concern that the wayside horn may draw the motorist's attention toward the source of the noise at the grade crossing, and away from the train. However, we believe there is an actual benefit at active crossings in drawing a distracted driver's attention to the crossing, since the flashing lights would be observed.

[3] The draft standard can be found at: http://www.tc.gc.ca/railway/publications.htm.

circumstances of the crossing, but is usually in the 20 to 30 second range. It is noted that this recommendation will lead to conflicts with the existing quarter-mile whistle posts when train speeds are less than 30 mph. If design warning times for a crossing are shorter than the whistle time from the quarter mile whistle post, it is recommended the whistle post be moved closer to the crossing. If it is not, the delay in activating the WSH (and associated delay in allowing the WSH to test its self monitoring of suitable sound output) might result in the locomotive engineer assuming it is healthy because the 'healthy' light is flashing at the whistle post but deactivated later if the WSH output is below the required threshold.[4]

We believe the 55 second maximum warning time allowed in RTD10 for active crossings is an adequate upper limit for the WSH. This would allow trains with a temporary slow order of 15 mph to approach the crossing without an interrupted WSH operation. It is recommended that the WSH should be activated with at minimum a 4 second delay, but enough delay to provide at most the design warning time for the crossing. It should be deactivated when the lead locomotive passes through the crossing, subject to the following time constraint. If the train is not detected to have passed through the crossing within the 55 second maximum recommended in RTD10, the WSH should turned off and the health monitor system triggered to provide the locomotive engineer with an indication that the system has been turned off. For the Saguenay crossings, the WSH would be activated 5 seconds after the FLB and deactivated no later than 55 seconds after the FLB has been activated. At the CFRS operating speed of 30 mph, the Saguenay WSHs would normally be on for 25 seconds.

2.3. Directionality: Data and Issues

Fann [2000] has taken directionality measurements for a wayside horn in a controlled environment—a parking lot with similar ground effects in all directions. His measurements were in general agreement with spot measurements we took at down road and down track at Saguenay, and therefore, Fann's more complete directional data were used in the directional characterization of the Saguenay WSHs. Fann's data are presented in Table 1.

Table 1
Directionality data from Fann's WSH measurements

Orientation	SPL @ 61 m. (dBA)	SPL Relative to 0.0° orientation (dBA)
0.0°	89.8	0.0
22.5°	86.8	-3.0
45.0°	83.2	-6.6
67.5°	79.6	-10.2
90.0°	75.0	-14.8

Source: Fann, 2000.

The directionality of the WSH is one source of its appeal for community noise reduction. However, it has also been the source of some safety issues previously raised in the literature (see section 1.1).

[4] The Gering, Nebraska study [Multer and Rapoza, 1998] encountered similar situations with slower trains (28 mph and lower) reaching the whistle post before the CWT signals were activated and resulted in the locomotive engineering blowing the locomotive horn and duplicating the later WSH's activation.

While none of the directional issues were relevant in the Saguenay installations, they are discussed from the perspective of other potential installations for the technology. Directionality issues discussed in the literature have resulted in two interpretations of the term. The first is the lack of directional information on the train's approach when a wayside horn is used. The second is the directional pattern of the wayside horn that no longer provides a warning to trespassers down the track. We discuss the trespass issue first.

2.3.1 Trespassers

One of the factors in Transport Canada's guidelines for whistle bans is that fencing should be used when trespassing is in evidence beyond the grade crossings. While the locomotive engineer can blow the horn when trespassers are spotted, they might not be spotted soon enough at night and/or in high train-speed areas. The standard whistling at grade crossings is an indication to trespassers that a train is nearby. The wayside horn as it presently exists would provide some warning down-track, but its focusing pattern means it would have only marginal effectiveness beyond that of the crossing bell.

Trespassing was not an issue at Saguenay as the CFRS right of way is fenced along the residential areas in the city. In locations where trespassing is a consideration, the alternatives to overcoming this limitation are to increase the loudness of the crossing bell or to add a down-track sound component from the wayside horn. A third option to consider is to use the locomotive bell in whistle ban communities during periods of low visibility (e.g. at night or in fog). Trespass considerations were not part of our terms of reference, but the cost/effectiveness of the three alternatives could be explored analytically and in conjunction with future WSH installations that involve trespass issues.

2.3.2. Train Approach Direction Information

Discussions of the importance of directionality must acknowledge that the locomotive horn does not provide perfect information. Directional information is only available from a locomotive horn to the extent that people can judge the source of the sound. The horn's frequency spectrum does cover the range where pedestrians can reasonably judge the source direction, but it is more difficult to judge directionality inside a closed vehicle.

Information about the arriving direction of a train is important in a few situations. For passive grade crossings, the direction from which the train is approaching is an important cue that the locomotive horn provides. Visual confirmation of train arrival is often made before reacting at passive crossings. However, the wayside horn is not a candidate for passive crossings. In approaching an active crossing, it might actually be better to draw the attention of a distracted driver to the visual warning signs at the crossing than away from it. In this regard, a wayside horn might be a better alerting mechanism than the locomotive horn.

Concerning drivers and pedestrians stopped at a crossing, there are at least two situations where directionality might be important:

1. crossings with near-by intersections that allow left hand turns, and
2. second train scenarios.

The geometry of a left turn intersection at a grade crossing is illustrated in Figure 7. The left turn scenario becomes a problem if there are visual trains approaching (or just standing) from the right side and another unseen train is approaching from the left side. Drivers judge they can safely beat the visible train to the right but do not have a good sight angle for the left-side train and neglect to look. It is possible that directional information is only important if people can not depend on the warning signal to be an accurate indication of imminent train arrival (and thus need to seek visual confirmation). If a wayside horn were only heard 15 seconds before a train's arrival and drivers became confident in this relationship, it might not be necessary to provide directional information. However, developing such confidence would be a long process and would primarily affect local drivers who experience the wayside horn. In the short term, it might be desirable to provide ancillary information on the approaching train(s) direction at those crossings with acute angles and more than one track. LED moving-arrows along the gate is an obvious solution that might involve a reasonable incremental cost. Again, this aspect was not in our terms of reference. Interested readers are directed to the Direction 2006 *Second Train Warning Study* [IBI Group, 2004].

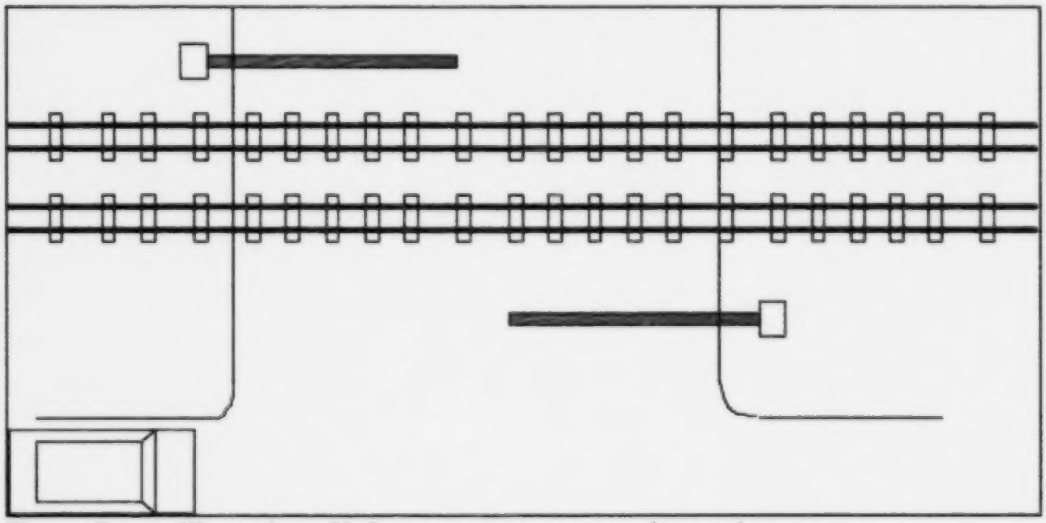

Figure 7 Illustration of left turn geometry at a grade crossing

The wayside horn is better positioned than locomotive horns to alert pedestrians of second trains; however, its reduced output and focus down the road, results in a lateral sound output that also might not be heard over the background noise of the first passing train. If the WSH is to be taken as an effective indication of a second train, the previously discussed (section 2.2.2.2) problems of reliability and variability of warnings would have to be resolved. If the WSH is proven to be a reliable indication of train arrival, the lack of directionality in the signal might not be important.

If the WSH could be heard over the background noise of a passing train, it could be possible to differentiate the sound and/or temporal pattern of the WSH under second train situations so that the users of the grade crossing become accustomed to the relationship with a second train, rather

than thinking it is a false warning. Second trains were not an issue on the CFRS single track line and Direction 2006 has undertaken previous studies that specifically addressed second train issues [IBI Group, 2004]. It is recommended that Transport Canada assess the feasibility of WSHs being heard and potential benefits of a differentiated sound characteristic for second trains to determine if additional tests are warranted in conjunction with any future WSH installations where second trains and pedestrians are involved.

3. SCHOOL BUS CHARACTERIZATION

This discussion in this section is only relevant to non-gated crossings, to the extent that WSH technology is considered as a substitute for locomotive horns at non-gated crossings with high speed trains. It is not directly relevant to the Saguenay situation. School bus characterization was included in our terms of reference because they have not been characterized to the extent that automobiles and trucks have.

The Volpe Center [Rapoza, et al., 1999] derived insertion losses for a range of personal road vehicles. The internal background noise was measured by English et al. [English et al. 2003] for a range of conditions in one vehicle. Robinson characterized the insertion loss and background noise of intercity highway trucks [Robinson, et al., 1997]. In a National Transportation Safety Board [NTSB, 1998] safety study of passive crossings, field measurements were undertaken in a school bus with a locomotive horn, set at the FRA regulatory requirement of 96 dB(A) at 100 ft. (30.5 m.). It found that "in one test vehicle (a 1997 Thomas/Ford school bus) the sound level of the train horn was not audible above the noise level of the idling engine" but details of the insertion loss and background noise were not published. Marcotte, et al. made background noise measurements of school buses with children on board [Marcotte, et al., 2004]. Our scope of work included taking in-vehicle measurements of a school bus to characterize the insertion loss and background noise level.

Background noise measurements were made for conditions of engine idling, and two other incremental sources of noise. The first increment (I+DF) was with the driver's fan on (on or off were the only choices). The bus also had separate auxiliary fan that blew air on the windshield to defrost it. The control for this fan also consisted of an on/off switch. The second increment was with both fans on (I+DF+AF). Figure 8 illustrates the frequency spectra and magnitudes of the three noise environments.

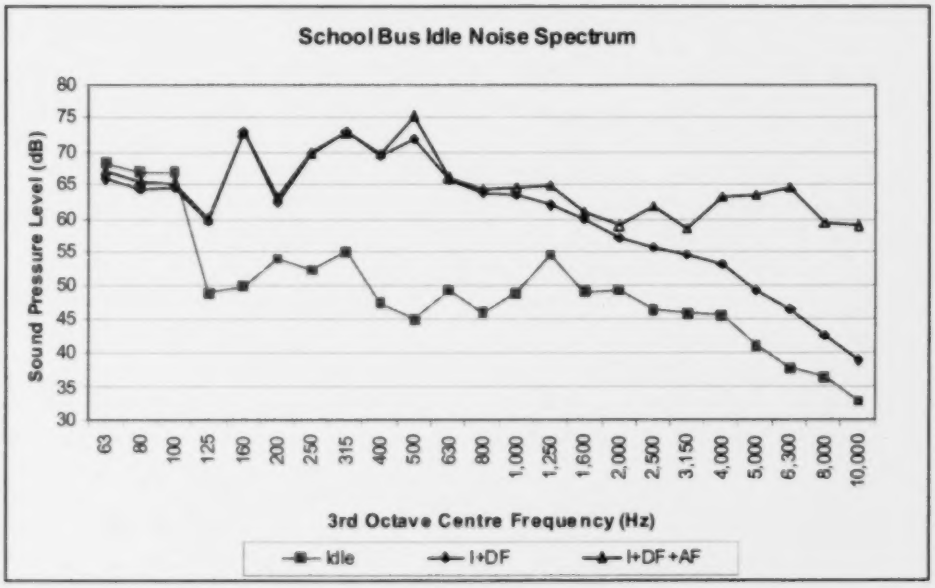

Figure 8 Background noise in stationary school bus

The noise in the school bus is significantly higher than in the passenger vehicle reference cases used in the locomotive horn study [English, et al., 2003]. The school bus's SPL is higher across the full frequency spectrum for both the engine idle state and the fan on state than the SPL of the passenger van used in the locomotive horn study. On the other hand, the school bus background noise measurements are lower than the background noise measurements made inside heavy duty truck cabs by Robinson [Robinson et al., 1997].

The insertion loss measurements were made with the microphone on the driver's seat at head level. The speaker was positioned 10 m. from the bus at two different angles on the driver's side as well as perpendicular to the door on the door side of the bus. The average results with the door closed and open are illustrated in Figure 9.

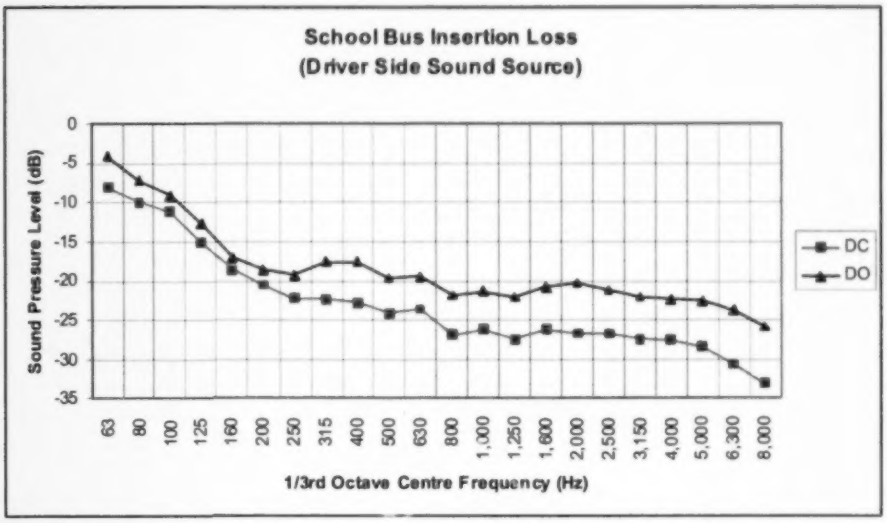

Figure 9 School bus insertion loss with door closed and door open

When stopped at a grade crossing, the driver is required to open the bus door. The insertion loss was essentially eliminated when the sound source was on the door-side of the bus and the door was open. However, the improvement was far less significant when the sound source was on the driver-side of the bus. Thus, the locomotive horn on a train approaching from the driver-side would be much less likely to be heard than one approaching from the door-side. Similarly, the WSH would be much more likely to be heard if mounted on the door-side. Applying our alerting criteria of receiving a signal which is 9 dB above the masking level of the background noise (S/M > 9 dB), indicates that a school bus driver with the door open and driver's fan on would not be alerted if the WSH were mounted in the highway median on the driver's side. If the fan is shut off, the WSH would be heard with a high S/M ratio over an idling engine.[5] The high noise levels originating from the children on school buses reported by Marcotte [Marcotte, 2004] were also considered. The noise characteristic of the children would mask the upper frequencies, but the

[5] We were told that the present Canadian Standards Association's *School Bus Standard* (D250-2000) recommends that school buses built after April 1, 2000 be equipped to automatically shut off the auxiliary fan when the door is opened.

frequencies below 800 Hz would not be masked. Thus, the WSH would be heard with their characterization of children's noise if the fans are turned off.

4. SAFETY EFFECTIVENESS

4.1. Stopped Vehicles

Safety equivalence of alerting levels in vehicles stopped at the crossing is readily attained by WSH. The locomotive is much farther from the crossing when it must be heard and the CFRS horn is (like most N.A. locomotives) mounted mid-locomotive. English et al. found that the mid-locomotive position leads to deterioration of sound level to the front of the locomotive, more significantly at higher speeds but also at 30 mph. As a consequence, the 12 dB SPL advantage measured for the locomotive horn is mitigated to the front when approaching at 30 mph. Also the farther distance required from locomotive to vehicle than WSH to vehicle, means that the WSH can be 30 dB lower than the locomotive horn to be safety neutral.

The WSH's position will affect its SPL for vehicles at the crossing. As indicated in section 2.3, the directionality of the WSH's output means that there is a 15 dB reduction in SPL to the side. Thus, a position on the near side of the crossing will have reduced SPL to the first vehicle at the gate. Positioning the WSH on the far side of the crossing will eliminate the shielding effect for the stopped vehicles but be farther away from approaching vehicles farther down the road. At Boul. Talbot, the CFRS and MTQ installed slave speakers on the far side of crossing in addition to main speakers on the near side of the crossing. This allowed the far-side speakers to be focused on the stopped vehicles and the nearside speakers to be focused on approaching traffic. The SPL received inside a stopped vehicle at Talbot is higher than is received from an approaching locomotive.

St. Paul had only one speaker per direction, mounted on the near side of the crossings. The 15 dB reduction from the speaker's focusing means that a lower SPL is present for stopped vehicles than at Talbot. Nonetheless, it exceeds the SPL available to a stopped vehicle from an approaching CFRS locomotive. The greater distance between locomotive and vehicle combined with the loss of sound in the direction of travel from a horn that is mounted mid-locomotive results in about a 20 dB lower SPL than the WSH produces fro a vehicle requiring a 10 second clearance time.

The safety-equivalence criterion applies to all vehicles. Robinson's measurements of insertion loss and background noise in truck cabs at idle indicate that the S/M ratio for the WSH mounted perpendicular to the truck on either side of the road would not exceed our +9 dB S/M criteria. However, since the WSH provides a higher SPL to the stopped vehicles than would an approaching CFRS locomotive horn, the WSH exceeds the safety-equivalence criterion even if it doe not meet our alerting criterion.

Also as noted in Chapter 3, the speaker placement can affect the effectiveness of the alerting signal for school buses. If the WSH is mounted on the curb-side of the road, the sound would be originating from the door-side of the bus with the open door. The WSH would be heard in all of the background noise scenarios discussed in Chapter 3. Since road-side mounting of the WSH is almost always the case (due to availability of a mounting mast) this finding of school buses benefiting from a road-side installation does not lead to any recommendation for change. We also note that additional slave speakers could be mounted in the centre median.

Finally, we note that the above discussion is not directly applicable to the Saguenay crossings. Both crossings have double gates which provide a full width barrier, and median curbs to prevent driving around. Thus, the safety issue of risk takers in stopped vehicles at the crossing is not relevant.

4.2. Approaching Vehicles

An important element of the collision data is information that allows one to classify the contributing causes as either risk taking or distracted drivers. Constant warning time and all other aspects of the guidelines for whistle bans address the risk takers, to either provide better information to them or to prevent them from taking risks. The measures do not address the distracted driver who might be alerted by a locomotive horn.

The Direction 2006 study of human factors [Caird, et al., 2002] provides some insight to the relative balance between risk takers and distracted drivers. Their Table 6.1, which categorizes FRA accident data for the interval 1999 to 2001, indicates 203 incidents of unintentional intrusions, compared with 151 incidents of deliberate intrusion and 188 undetermined. The numbers indicate alerting is important; however, the analyses did not isolate the role of active crossings in the data. It is possible that the majority of distracted driver collisions occur at passive crossings. It would be desirable to reassess the data to see how many *distracted driver* causes occur at active crossings in order to assess the importance of providing a warning down-road to alert drivers approaching active crossings. However, another Direction 2006 study [Saccomanno, et al. 2003] provides some indication that alerting is important at active crossings. They found a statistically meaningful relationship between posted highway speed and grade crossing collisions at active crossings. One explanation for this link is that the higher approach speed gave less time for distracted drivers approaching the crossing to be alerted. The same study did not find posted speed to be a statistically significant parameter at passive crossings.

Regardless of the degree of problem associated with distracted drivers at active grade crossings, it is known to exist at some level. In these cases, the wayside horn would only be safety neutral to the extent that it provides equivalent warning to that of a locomotive horn. Thus, the remainder of this section compares the alerting characteristics of wayside horns and locomotive horns.

The discussion of alerting is only relevant at St. Paul since Boul. Talbot has preemption circuits that are interlocked with the adjacent intersections to prevent drivers form approaching the crossing when it is activated.

The safety effectiveness of the horns are assessed on the basis of the sound pressure levels produced at the road vehicle at that point in time when a driver hearing the warning can react and bring the vehicle to a stop before reaching the crossing. Our comparison of safety effectiveness follows the same assumptions used in our previous locomotive horn study. It considers two scenarios:

1. A driver with fast response time and dry pavement conditions.
2. The more demanding driver response times and braking rates assumed in highway safety design.

Other assumptions that follow those used in the locomotive horn study 'base case' are:

- average insertion loss of vehicles tested by the Volpe Center
- internal noise conditions for a vehicle approaching on pavement at 60 to 70 km/h with the internal fan on position 3 (of a maximum of 4).
- alerting threshold at a sound level that is 9 dB above the masking level of the background noise.

As discussed in 2.3, the WSH produces a SPL output down the road which is about 12 dB lower than the locomotive produces to the side. The higher output of the locomotive horn is mitigated to some extent when compared with the WSH, because the locomotive is farther from the crossing when it must be heard (see Figure 10). This impact will be greater the higher the speed of the train. In the case of the two crossings at Saguenay, the train speed is 48 km/h (30 mph).

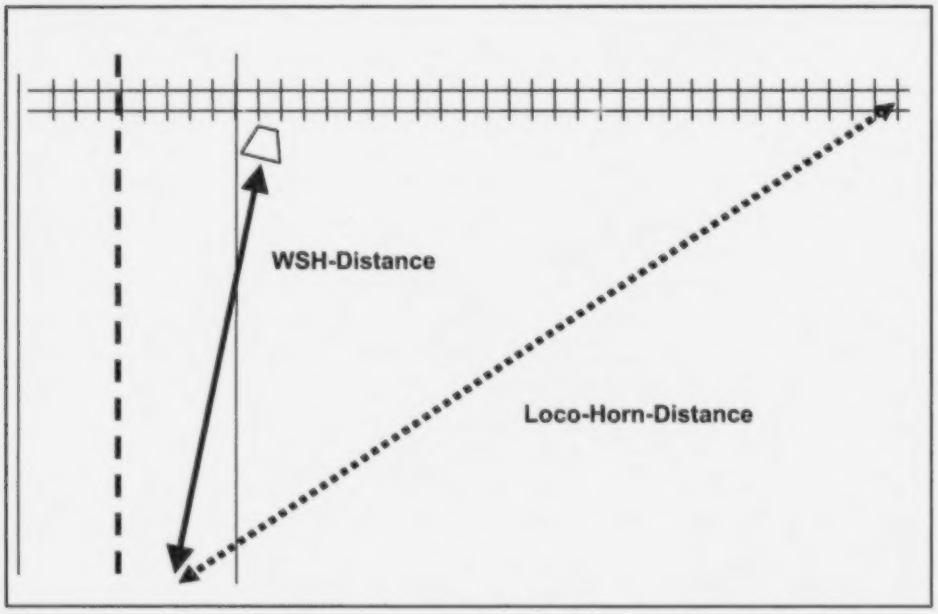

Figure 10 Warning distance comparison for WSH and locomotive horn

The SPL produced at increasing distances from the Boul St. Paul railway crossing is compared in Figure 11 for three scenarios: 1) a single-speaker WSH, 2) a CFRS locomotive horn approaching at 30 mph, and 3) a WSH main speaker combined with a second slave speaker mounted 30 m. farther down the road. The alerting threshold for our base case scenario is also shown in the figure over the distance associated with the three alerting scenarios. The fast-response and dry pavement condition leads to a distance of 40 m. while the 'highway design' conditions lead to a distance of 103 m. One can see that both horns exceed the minimum threshold level (SPL-Crit) associated with base case over this distance; however, the locomotive horn produces a higher alerting level.

There are a wide range of possible conditions that might exist for approaching drivers. The higher the alerting SPL, the higher are the number of scenarios in which a driver would be

alerted. Thus, the existing CFRS locomotive has a higher probability of being detected under the full range of scenarios than does the WSH. Given the lower level of alerting from the St. Paul WSH installation, we assessed the warning equivalency at St. Paul of adding a second speaker in each direction. There were light standards at Boul. St. Paul located in the median at a distance of 30 m. from the crossing and it was convenient to locate the slave speakers on those masts. Our analysis indicated (top line of Figure 11), the SPL would be equal to the locomotive horn over the distance range of interest. CFRS and the city of Saguenay did install slave speakers at 30 m.

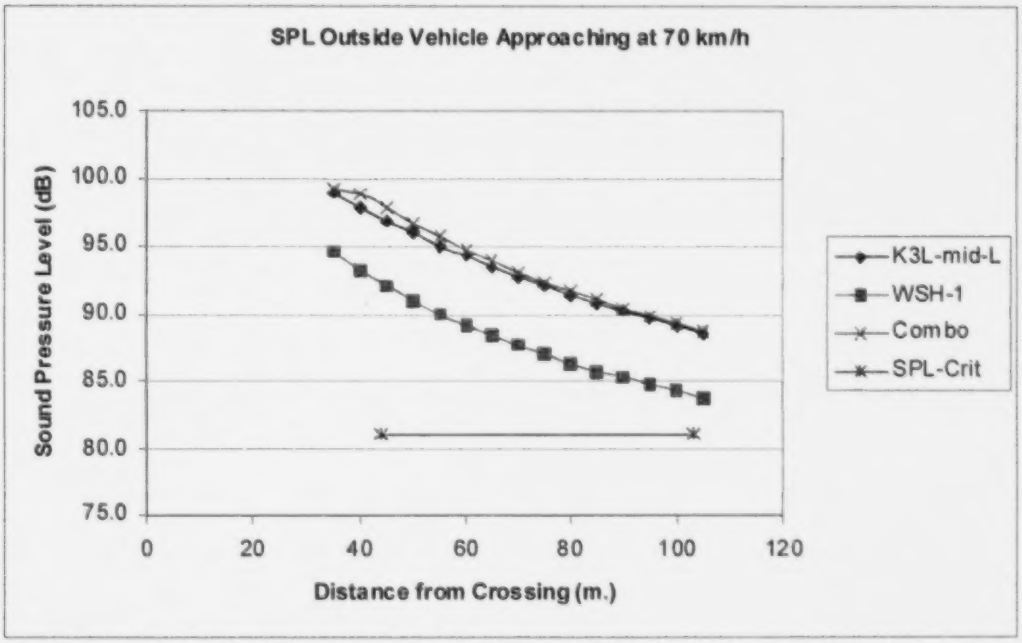

Figure 11 Alerting SPL comparison at St. Paul

The alerting level of the WSH was assessed on site by taking sound measurements inside a vehicle (2006 model RAV4) with the fan on high while approaching St. Paul crossing. Measurements were taken before and after the slave speakers were added at locations 30 m. down road on each side of the crossing. Under before conditions (no slave speakers), the WSH was found to be above the alerting level at the stopping distance associated with a fast response driver and dry pavement, but just barely detectible at the distance associate with normal highway design criteria.

Figure 12 and Figure 13 illustrate the spectrograms of the WSH sound characteristics against the background noise inside the vehicle (fan on high and radio off) on a 50 km/h approach to the crossing. Figure 12 is the WSH without slave speaker, and Figure 13 is the WSH with slave speakers.

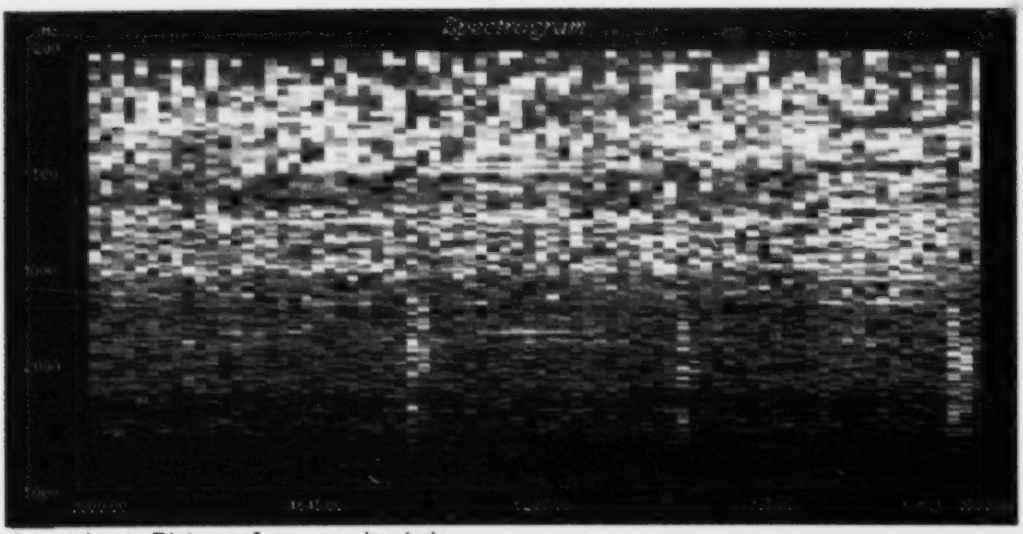

Figure 12 Spectrogram of the in-vehicle sound recording without slave speaker

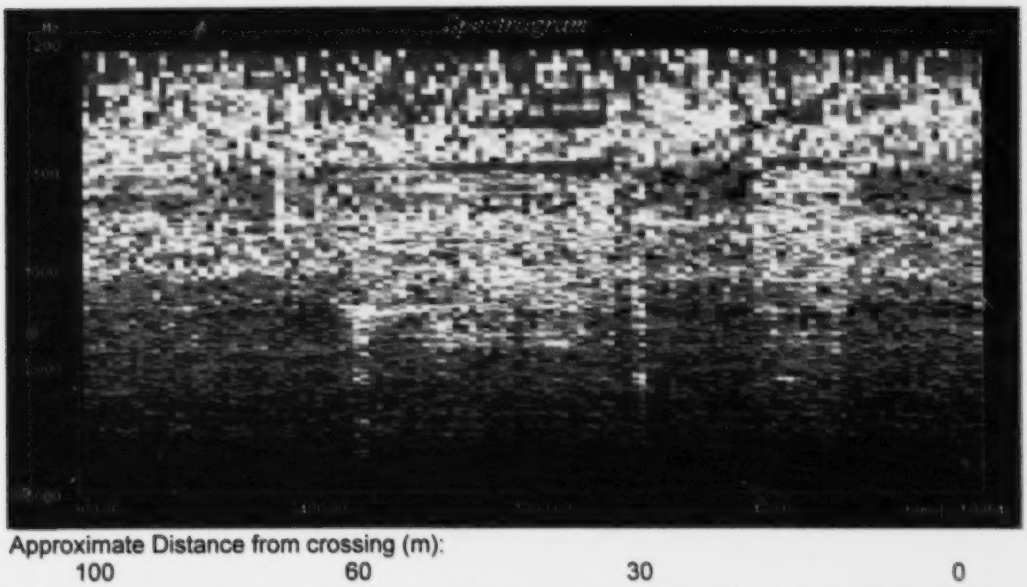

Figure 13 Spectrogram of the in-vehicle sound recording with slave speaker

The vertical axis of the spectrograms is the frequency of the recorded sound measured in Hertz (Hz) and displayed between 200 Hz and 5,000 Hz. The horizontal axis is time in milliseconds with the first mark on Figure 12 at 3,000 milliseconds (or 3.0 seconds) and the last mark at 9.58 seconds. While the chart is shown on a time scale, the distance from the crossing gate is known, as indicated in the second distance scale presented below the plots. The third dimension of the plots is the intensity of the sound, which is indicated by colour. Colour varies with intensity from black (lowest sound level) to purple, then blue, then green, then yellow, and finally red (highest

sound level). The background engine and fan noise is present throughout and has its highest intensity below 300 Hz. The higher the colour difference between background noise and signal, the more alerting the horn sound is.

The WSH without slave speaker (Figure 12) can be seen as distinguishable from the background noise for the time interval from about 6 seconds through to about 9.5 seconds. It has its highest intensity about 400 Hz and has an additional three discernable frequencies, the highest of which is at about 1,250 Hz. It can also be seen between 3 seconds and 4 seconds but at a lower intensity with only the 600, 800 and 1250 Hz components displaying a significant colour increment over the background noise. The horn is also blowing between zero and 2 seconds but the sound is indistinguishable from the background noise. The start of the short one-second blast of the horn between 3 and 4 seconds occur at about 45 m through to 30 m from the crossing. This is the location where a fast-response driver can respond and stop. The horn signal is distinguishable, although not as alerting as it is from 8.5 seconds on (which is about 15 m from the stop bar).

As can be seen in Figure 13, (WSH with added slave speaker) the sound intensity is improved at distances between 60 m. and 30 m. from the crossing (where the fast-response driver needs to hear it) and the warning sound inside the vehicle is discernable at 90 m. from the crossing.

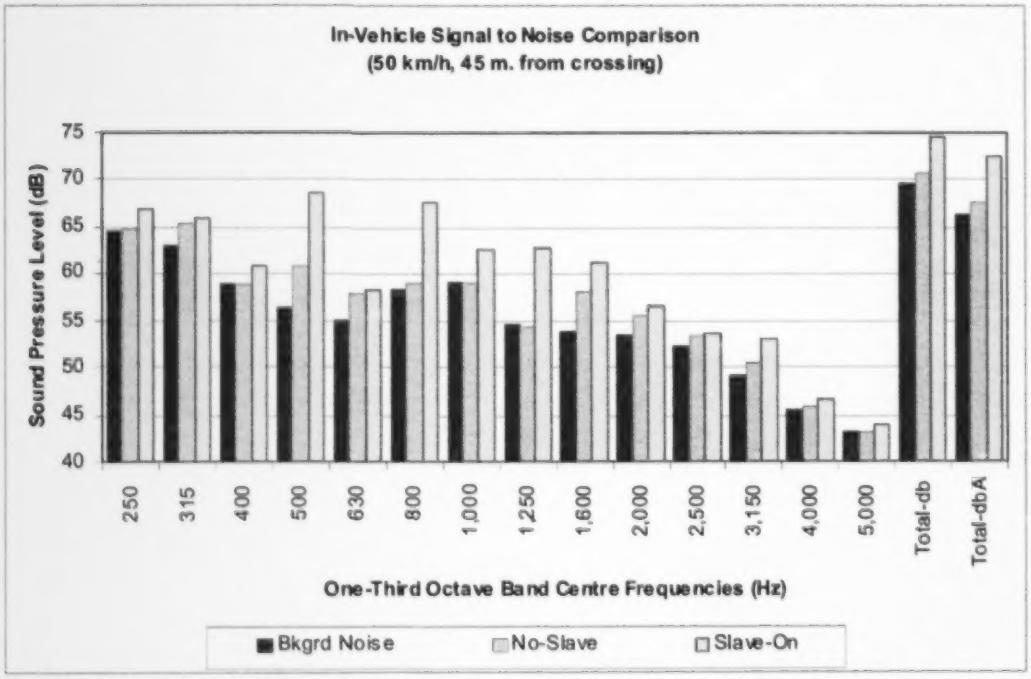

Figure 14 In-vehicle sound spectra comparison at 45 m. from St. Paul crossing

Figure 14 compares the frequency spectra of the WSH and WSH-with-slave-speaker to that of the background noise when the vehicle, approaching at 50 km/h was 45 m. from the crossing.

Whereas the previous spectrogram figures illustrated the signal characteristic with colour intensity, Figure 14 presents a snapshot of the signals with the intensity measured in one-third

octave bands. One can see that the WSH is about 4 dB above the background noise at 500 Hz. and 1,600 Hz. In comparison, the WSH with slave speaker is 10 dB above background noise at 500 Hz and 800 Hz., and is more than 4 dB above background noise for most of the spectrum.

5. COMMUNITY NOISE IMPACTS

Community noise impact is assessed on the basis of the sound exposure level (SEL), which describes the cumulative noise exposure from a single noise event for its entire duration. In calculating SEL, the noise exposure is normalized to a time duration of one second so that different noise events can be compared in terms of their sound energy. The boundary lines of equivalent community noise impact for the St. Paul and Talbot grade crossings are illustrated in Figure 15.

Sound Footprint Legend:

- - - - CFRS horn SEL=80 ——— WSH SEL=80
- - - - CFRS horn SEL=90 ——— WSH SEL=90

Figure 15 Community noise impact comparison (St. Paul – left, Talbot – right)

The solid lines in Figure 15 are the footprint of the wayside horn while the dashed lines are the footprint of the locomotive horn. The noise impact is that of two trains arriving (one from each direction). The black lines are the boundary of the impact area, while the red lines are the boundary of the severe impact area. One can see that the WSH has a significantly smaller footprint than the locomotive horn.

The WSH's footprint is broader at Boul. Talbot than at Boul. St. Paul because the Talbot installation has a second horn in each direction that is located in the highway median and directed towards the close range traffic. One can see that the noise footprint of the Talbot's WSH is significantly smaller than that of the locomotive horn and that the residential areas are not impacted by the noise of the WSH.

The added noise exposure with the slave speakers at 30 m. is compared with the locomotive horn's impact in Figure 16. While the footprint is larger than the single-pair scenario shown previously in Figure 15, the sound exposure level at Rue Bersimis (which is zoned industrial) is 10 dB lower with the WSH than from the locomotive horn. People judge a 10 dB reduction to be about half the sound intensity.

There was one noise complaint made after the slave speakers were installed. It came from a resident of a small apartment dwelling located on Boul. St. Paul, about 90 m. from the crossing. We took sound measurements at the location and found that the locomotive horn was louder at that location than was the WSH with slave speakers. However, the time sequence of events was such that the resident had six months of noise exposure with the WSH and no slave speakers before the slave speakers were added. The noise exposure at that location was increased with the addition of the slave speaker. However, had it been installed at the time of the initial conversion from locomotive horn to WSH, the resident would have experienced a reduction in noise exposure and would have been unlikely to have complained. Also, the slave speaker was located in the centre median because there was an available lighting mast at that location. Its orientation was focused on the approaching traffic, which resulted in it being directed at the apartment building. Had it been located on the side of the road, the apartment would have benefited from the side-attenuation characteristics of the speaker.

Sound Footprint Legend:

- - - - CFRS horn SEL=80 ——— WSH SEL=80
- - - - CFRS horn SEL=90 ——— WSH SEL=90

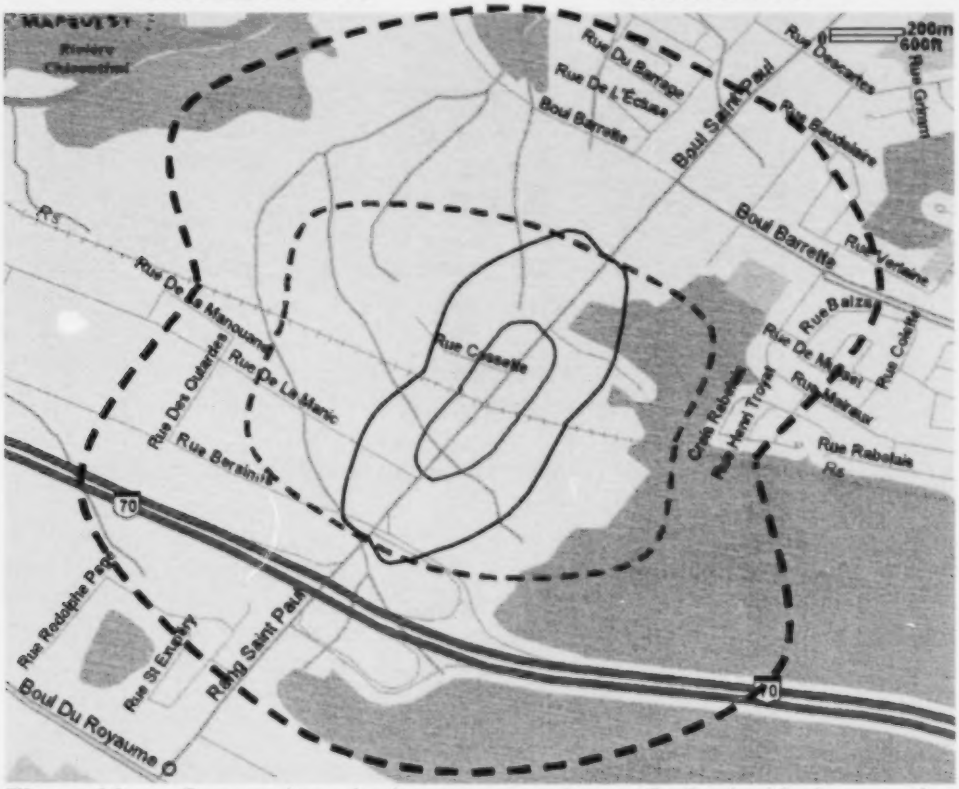

Figure 16 Community noise impact comparison at St. Paul with slave speakers at 30 m.

6. WINTER RELIABILITY

The performance of the WSH in a cold climate is important to the Canadian evaluation of the technology. The Saguenay region provides a climate similar to many parts of Canada. The average daily low in January and February is -20 °C and the average annual snow fall is 345 cm. For the 2005 – 2006 interval when the WSH systems were monitored, the minimum temperature was -30.1 °C (recorded on January 1, 2006).[6]

The speakers used in the WSH are designed to withstand winter conditions that are seldom exceeded anywhere on the Canadian rail system. The speaker drivers are specified to have an operating temperature range of -55C to + 85C and to survive water immersion for 96 hours without deterioration in sound quality. Thus, it is not the survivability of the hardware that is an issue, but the operating procedures that should be in place to safeguard the system in scenarios of icing or snow ingestion.

The WSH has a built in microphone that provides feedback to the system that the sound output is present once activated. If the sound pressure level falls below a threshold, a flashing light that is pointed down the track for the locomotive engineer to verify that the WSH is working is turned off. The reliability of the system was monitored by having CFRS locomotive engineers report any occurrences when the WSH "healthy" light was not activated on approach to the wayside horn crossings.

There was one occurrence at the start of winter when both WSH systems shut down completely and were out of service until repair arrangements were made a couple of weeks later. We were told that the deicing heater inside the speaker had created a problem on activation and that the prescribed remedy was to disconnect the heater and to remove the front grill so that it would not be susceptible to icing.

The main operating reliability questions are:

1. how much does the sound output deteriorate with icing or snow ingestion, and
2. at what level of deterioration should the microphone feedback loop indicate the WSH is not "healthy".

It is very difficult to depend on natural weather conditions to make these observations. Thus, freezing rain and snow ingestion conditions were simulated at freezing temperatures in order to assess their impact on the Saguenay WSH speaker system. SPL measurements were made at a distance of 61 m. from an isolated WSH. The tests were conducted off the road with a snow bank between the source and microphone. Thus, the ground effects were not as significant as previously observed with sound reflections from the paved road. All other speakers but the test speaker were deactivated for the measurements. The four conditions and associated SPL measurements were:

a) Normal speaker (without grill) 90 dBA
b) Speaker with grill openings filled with ice (about 6 mm. depth) 78 dBA

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[6] Weather data recorded at Bagotville airport, which is 15 km southwest of Saguenay.

c) Speaker iced as in b), plus a 4 mm iced thickness inside the grill 78 dBA
d) Open speaker with snow plugged around the entire cone 62 dBA

Thus, icing of the grill produced a 12 dB drop in SPL, while a snow plug condition (see Figure 17) created a 28 dB drop in SPL. The added depth of ice inside the grill resulted in no discernable loss beyond that of the iced grill.

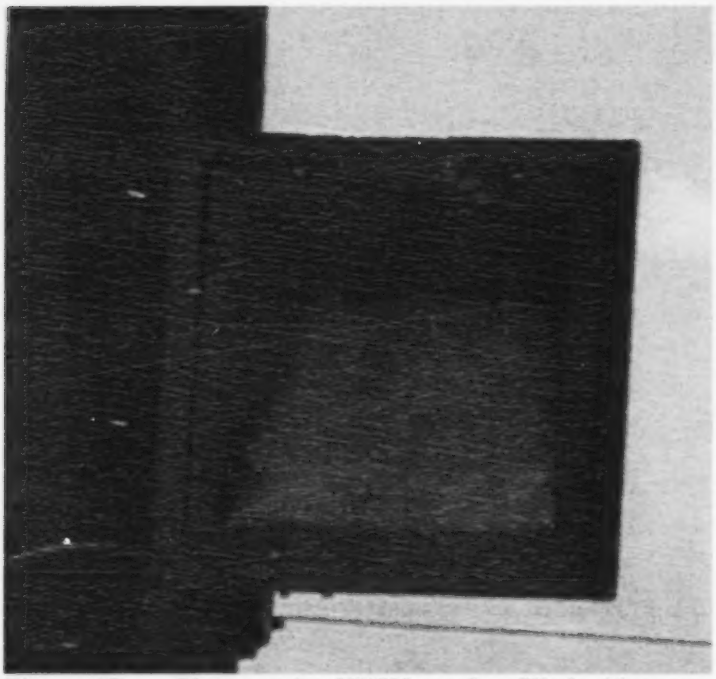

Figure 17 Photograph of WSH speaker filled with snow

While completely turning off a speaker produced a 'fault' detection on the health monitoring system, the level of deterioration involved in our tests did not get detected as a reportable problem by the health monitoring system. It is possible that the signal level received from other three working speakers by the microphone on the snow-plugged speaker was enough to exceed the 'fault' threshold.

It is recommended a higher detection threshold for the microphone feedback loop in the health monitoring system. The output level of 92 dB(A) at 30.5 m. (100 ft.) is already at the low end of desirable alerting levels for approaching drivers. It is recommended that the health monitoring system be set to activate when the SPL output from any speaker either drops by 3 dB from the installed certification level, or falls below the equivalent output of 92 dB(A) at 30.5 m. The WSH system has a volume control and verification of the 'healthy' threshold can be undertaken simply by reducing the sound output with the volume control and measuring the speaker's SPL output. The SPL output could either be measured at 30.5 m. or the built-in microphone could initially be calibrated for 30.5 m.-equivalent output. We further recommend that any installation in regions susceptible to freezing rain or blowing snow have this threshold of the health monitoring system verified once a year in the fall or early winter.

7. CONCLUSIONS AND RECOMMENDATIONS

This study has focused on the specific conditions that exist at the two crossings in Saguenay. During the course of the study, recommendations were made to add slave speakers at one of the two crossings evaluated. This recommendation was acted on and the before and after measurements were made and presented in our report. All of the recommendations that follow are of a generic nature and apply to any future installations of WSH technology in Canada. The only recommendations that might affect the present installations in Saguenay are the recommended activation time and duration limit for WSHs (recommendation 4) and the recommendations associated with the 'health' monitoring system (recommendations 7 and 8).

In a safety-neutral comparison with the existing CFRS locomotive horns and under Saguenay conditions, the WSH provides a higher SPL to stopped vehicles. However, it provides a lower SPL to approaching vehicles at the location down the road where the driver needs to hear it in time to react and stop. In terms of the sound output level required to attain the necessary auditory alerting inside an approaching vehicle (for Saguenay conditions and irrespective of the regulatory minimum requirement), the WSH is considered adequate for situations of fast driver response time and dry pavement, even though it provides a lower SPL than the locomotive horn. However, the WSH would alert far fewer drivers than the CFRS locomotive horn for the more conservative assumptions of slower driver response and wet pavement. It is acknowledged that the minimum allowable output from a locomotive horn under the FRA horn rule would also alert far fewer drivers than would the CFRS locomotive horn under these conditions; however, the basis of comparison is the existing CFRS locomotives. Since the CFRS locomotive horns had SPLs that were consistent with other freight locomotives in Canada (see English, et al. 2003), our recommendation is generic to any future installations in Canada.

> **Recommendation 1**
> We recommend that, when WSH systems are being considered for grade crossings where approach warning is an issue, the benefits of additional slave speakers, or down-road positioning of the main speakers be assessed.

Since the fixed on-off pattern of the automated WSH has no ability to adjust to circumstances, and the existing railway whistling pattern itself has no safety basis, it is recommended that the normal locomotive whistle pattern not be used in future WSH installations. A fixed repeating pattern of 3.5 seconds on and 1 second off would have no intervals exceeding one second without warning, or requiring detection and recognition of the warning within the time interval of a one-second sound signal.

> **Recommendation 2**
> We recommend that future WSH systems in Canada use a fixed recurring on/off/on/off pattern with 3.5 seconds on and 1 second off while activated.

Recommendation 3
We recommend that WSH technology only be deployed at crossings that either have consistent warning times with few false alarms, or where the WSH can be tied into a separate activation system that can provide a consistent warning.

Since false alarms can never be totally eliminated, we believe the duration of the WSH warning time should be limited to be consistent with the recommendations made for active warning systems in Transport Canada's Draft Technical Standard RTD10. We believe the 55 second maximum warning time allowed in RTD10 for active crossings is an adequate upper limit for WSH installations. Also, the dilemma situation characteristic of North American grade crossing warning systems can be exacerbated if the WSH is activated immediately with the flashing lights; but can be avoided if the WSH activation is delayed.

Recommendation 4
We recommend that the WSHs be:
a) activated with a 4 second delay, and with enough delay to provide at most the design warning time for the crossing.
b) deactivated when the locomotive passes through the crossing, subject to the time constraint that if the train is not detected to have passed through the crossing within 55 seconds of activation, the WSH should be turned off and the health monitor system triggered to provide the locomotive engineer with an indication that the system has been turned off.

The design warning time can be shorter than the locomotive horn's warning time for slow trains (as initiated at the quarter-mile whistle post).

Recommendation 5
We recommend that the whistle posts be moved closer in to a distance that is consistent with the design warning time for installations with train speeds lower than 40 km/h (25 mph).

It would be possible to differentiate the sound and/or temporal pattern of the WSH under second train situations but the effectiveness of doing so is unknown.

Recommendation 6
We recommend that Transport Canada weigh the merits (within the framework of its research to date on second train accidents) of conducting additional research into the WSHs at second train sites. If warranted, an assessment of differentiated sound characteristics could be made at a future WSH installation involving frequent second train situations with pedestrians involved.

The WSH has a self checking mechanism that monitors the speakers' SPL outputs. The WSHs also have a volume control that allows one to easily lower the SPL output and assess the activation threshold which triggers an 'unhealthy' speaker indication.

Recommendation 7
We recommend that the health monitoring system on WSHs be set to activate when the SPL output from any speaker either drops by 3 dB from the installed certification level, or falls below the equivalent output of 92 dB(A) at 30.5 m.

Recommendation 8
We further recommend that any installation in regions susceptible to freezing rain or blowing snow have this threshold of the health monitoring system verified once a year in the fall or early winter.

8. RÉFÉRENCES

Caird, J.K., J.I. Creaser, C.J. Edwards, & R.E. Dewar, *Une analyse des facteurs humains dans les accidents aux passages à niveau au Canada*, Cognitive Ergonomics Research Laboratory, Département de psychologie, Université de Calgary, Transports Canada, TP 13938F, 2002.

Dodson, John, "Non-Train Railroad Crossing Accidents Related to School and Other Buses", *Proceedings, 4th International Symposium on Railroad Highway Grade Crossing Research and Safety*, Knoxville TN, October 1996. published April, 1997.

English, G.W., A. Russo, T.N. Moore et coll., *Évaluation de klaxons de locomotive : efficacité aux vitesses d'exploitation*, Transports Canada, TP 14103, juin 2003.

Fann, Mike, *Wayside Horn Sound Radiation and Approaching Motorist Audibility Evaluation*, Association of American Railroads, May 2000.

Gent, Steve J., Scott Logan, and David Evans, *Evaluation of an Automated Horn Warning System at Three Highway-Railroad Grade Crossings in Ames, Iowa*, (www.dot.state.ia.us).

Groupe IBI, *Système d'avertissement de l'approche d'un autre train aux passages à niveau*, Transports Canada, TP 14288F, 2004.

Keller, Amanda S. and Edward J. Rickley, *The Safety of Highway-Railroad Grade Crossings: Study of the Acoustic Characteristics of Railroad Horn Systems*, DOT-VNTSC-FRA-93-1, July 1993.

Marcotte, Pierre, Paul-Émile Boileau et Jérôme Boutin, *Étude de l'exposition professionnelle au bruit des conducteurs d'autobus scolaires*, Rapport R-364, Institut de recherche Robert-Sauvé en santé et en sécurité du travail, mars 2004.

Multer, J., and A. Rapoza, *Field Evaluation of a Wayside Horn at a Highway-Railroad Grade Crossing*, DOT-VNTSC-FRA-97-1, June 1998.

Rapoza, A., and E.J. Rickley, *The Safety of Highway Railroad Grade Crossings: The Effectiveness of Railroad Horn Systems*, Report No. DOT/FRA/ORD-95/, U.S. Department of Transportation, Federal Railroad Administration, Washington, DC, 1995.

Rapoza, Amanda S., Thomas G. Raslear, and Edward J. Rickley, *Railroad Horn Systems Research*, DOT-VNTSC-FRA-98-2, U.S. Department of Transportation, Federal Railroad Administration, Washington, DC, January 1999.

Raub, Richard A. Roy E. Lucke and Thomas Thunder, *Evaluation of the Automated Wayside Horn System in Mundelein, Illinois*, Northwestern University Center for Public Safety, January, 2003.

Robinson, G. S., J. G. Casali, S. E. Lee, *Role of Driver Hearing in Commercial Motor Vehicle Operation: An Evaluation of the FHWA Hearing Requirement*, Sep 1997. Federal Highway Administration, Washington, DC.

Roop, Stephen S., *A Safety Evaluation of the RCL Automated Horn System*, Texas Transportation Institute, Rail Research, Texas A&M University, May 2000.

Rudnick, I., "The propagation of an acoustic wave along a boundary," *Journal of the Acoustics Society of America*, 19 (2), 348-356, 1947.

Saccomanno, Frank, L. Fu, C. Ren and L. Miranda, *Détermination des «points noirs» parmi les passages à niveau : Phase I*, Université de Waterloo, Transports Canada, TP 14168, 2003.

Schoppert: D. W. and Hoyt, D.W. *Factors influencing safety at highway-rail grade crossings*, Report No. 50, National Cooperative Highway Research Program, Highway Research Board, Washington, D.C., 1968.

University of Central Florida, Noise Laboratory, *Comprehensive Community Noise Model User's Manual*, 2002.

U.S. DOT, FRA, *Use of Locomotive Horns at Highway-Rail Grade Crossings; Interim Rule*, 49 CFR Parts 222 and 229, Federal Register Proposed Rules, Vol. 65, No. 9, January 13, 2000.

U.S. DOT, FRA, *Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule*, 49 CFR Parts 222 and 229, Federal Register Proposed Rules, Vol. 65, No. 9, April 27, 2005.

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